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THE WINTER ANTICYCLONE OF THE GREAT BASIN¹

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In several respects the characteristics of this anticyclone are similar to those belonging to the so-called semipermanent anticyclones of the globe. Like the great Siberian anticyclone, it is clearly of seasonal origin and must be considered as the continental extension of the northeast Pacific anticyclone which has its greatest development in August in about north latitude 40° , west longitude about 150° .

The annual march of atmospheric pressure over a semiarid continental region, such as that of the Great Basin, is, of course, somewhat different from that over the ocean. Figure 1 shows the annual march of the monthly means of pressure at Boise, Idaho, a representative Great Basin station.

Pressure in the Great Basin rises from a minimum in May to a maximum in December, whereas pressure in the North Pacific anticyclone reaches its yearly maximum in August and diminishes thereafter to its minimum in January when its geographical center is about 950 miles almost due west from San Francisco, Calif. From that position offshoots may and do readily pass northward along the California coast, inland over Washington and Oregon, and thence by an easy step to the G. B. A.

The background for a clear understanding of the causes which conspire to create and maintain this anticyclone must be sought in the larger features of the general atmospheric circulation and the normal pressure distribution of the Northern Hemisphere. The large features of pressure distribution are: Low pressure in equatorial regions, a belt of high pressure surrounding the globe about latitude 35° in both hemispheres in which the high pressure is not continuous but broken up into separate centers of higher pressure over the oceans of which in the Northern Hemisphere the Azores high over the eastern Atlantic and the northeast Pacific high, already mentioned are prominent examples. There is also a second belt of low pressure near the sixtieth parallel best developed over the northeast Pacific and the same quarter of the Atlantic.

The belts of high pressure with which we are most directly concerned differ in the two hemispheres, the

one in the Southern Hemisphere is roughly parallel with the Equator, while that of the Northern Hemisphere is of irregular outline and exhibits the greatest differences as regards breadth, latitude, and inclination to the Equator. These differences are due entirely to the great preponderance of land surface in the Northern as compared with the Southern Hemisphere. The basic cause of the G. B. A. is its geographic position on the western margin of the North American Continent in a dry region where the solar radiation in winter is largely reflected by the snow cover. The naturally large terrestrial radiation of the region also is at a maximum in winter, hence a part of the prevailing high pressure is purely a radiation effect. The region around the station Boise, Idaho,

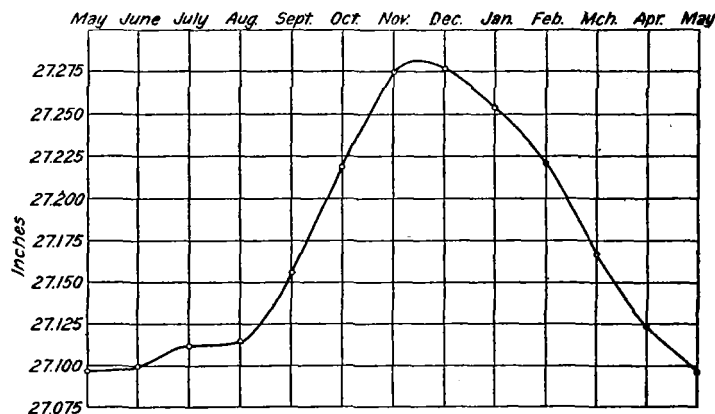


FIG. 1

seems to be one of large radiation opportunity and for that reason it has been chosen as the representative station of the Great Basin region.

The G. B. A. is at its greatest intensity in January; its maintenance and appearance of permanence are brought about substantially as follows: At least three important factors in the maintenance of the G. B. A. may be mentioned, first is the presence a few hundred miles offshore of the semipermanent anticyclone of the northeast Pacific offshoots from which readily pass inland in the rear of a cyclone moving eastward along the border between the United States and Canada, the normal course followed by oceanic storms which come in from the Pacific; second, as already mentioned, the terrestrial radiation of the Great Basin region by reason of its aridity is large and the cooling of the lower layers of the atmosphere due to this cause is augmented in no small degree by the loss of incoming solar radiation by reflection from the snow

¹ The term "Great Basin" is almost universally used by physiographers to include that extensive area of interior drainage that lies near the western margin of the continent. It is bounded on the north by the Columbia River Basin, on the east by that of the Colorado and on the west by the basins of the streams that have their source in the high Sierra. It is not a single cup-shaped depression gathering its waters at a common center, as the title might suggest, but rather a broad area of irregular surface, naturally divided into a number of independent drainage districts. Its extreme north-south length is about 800 miles and its widest part, say, in latitude $40^{\circ} 30' N.$, is 572 miles. The political subdivisions within it are almost the whole of Nevada, the western half of Utah, a strip along the eastern border of California, and a rather large, though for our purpose unimportant, area in the southeastern part of that State; also a rather large area in southeastern Oregon and, say, the southern half of Idaho. The locus of the Great Basin anticyclone (for which we shall use the abbreviation G. B. A. henceforth), is, however, confined to the north half of the basin.

cover in winter. These causes conspire to build up pressure over the Great Basin and to maintain it at a high level for 10 days to 2 weeks and even longer.

The anticyclone is dissipated temporarily when a succession of cyclonic storms from the Pacific or the Canadian northwest pass eastward along the border without the intervention of strong anticyclonic conditions. Each individual cyclone as it passes along the boundary is associated with a wave of falling pressure which extends some distance south of the cyclone center; thus it happens that at times so-called waves of falling pressure sweep over the Great Basin, the amplitude of the fall being larger in the northern than in the southern part of the basin. If, then, a number of consecutive impulses of falling pressure are received and there are no impulses of the opposite character to offset them, the center of the G. B. A. is progressively displaced to the southeast and finally disappears for a few days.

CHANGES IN FORM AND INTENSITY OF THE G. B. A.

As might be expected, the geographic position and intensity of this anticyclone are not the same in consecutive years. The variations most frequently experienced are shown in the series of small charts in Figure 2. Charts are also presented to show the contour of the isobars when the G. B. A. is absent.

Chart A is typical of the form of isobars in an ideal G. B. A., while charts B, C, and D are variations on the ideal type, of which perhaps C is the most important. In that type anticyclones from the Canadian northwest pass southeastward over the Missouri Valley and cold weather east of the Rocky Mountains and warm weather west of them result. This apparently abnormal temperature distribution may be explained as follows: It is an observed fact that in many anticyclones the cold air is confined to the air layers below the summit of the Rockies in Idaho and Montana; wherefore there is no westward overflow of cold air to the Plateau and Great Basin region.

In chart D—December, 1905—is shown the western center of a ridge of high pressure that extended from the Atlantic, off the Georgia coast, to the Pacific along the Washington and Oregon coast. This western center of high pressure acts much as an ideal G. B. A.

ISOBARIC FORMATION WHEN G. B. A. IS ABSENT

The four small charts, E, F, G, and H, show the types of pressure distribution in those months when the weather sequences were not favorable to the establishment and maintenance of the G. B. A. Chart E—January, 1909—shows a complete reversal from the usual anticyclonic conditions of January in the Great Basin, and chart F is much of the same order. The latter is made conspicuous by the fact that, although heavy rains fell in all California, not a single cyclonic storm passed inland south of the mouth of the Columbia River. Chart G—January, 1916—on the other hand, while pressure was generally low on the Pacific coast, several cyclonic storms passed inland over southern California, giving torrential rains in that part of the State. The last chart of the series is representative of a much weakened G. B. A. and also a month when the highest mean pressure was found over the Atlantic coast, end of the winter high-pressure ridge.

When monthly mean pressure charts for the Pacific shall become available, one will doubtless see that when the isobars of the Pacific coast have the form illustrated

by charts E and F the winter cyclone usually centered over the Aleutians will be found considerably to the southeast of its normal position. We may infer from the records of land stations that the center of the Aleutian Low in each of the months represented by the four charts in question was not far from the coast of Washington and Oregon. World-wide meteorological statistics now available show that the low pressure in January, 1909, 1911, 1914, and 1916 were not confined alone to the northeast Pacific and the west coast of North America.

Statistics of January mean pressure at Boise, the representative station of the G. B. A., are presented in Table 1.

TABLE 1.—Details of the Great Basin winter anticyclone

Year	Sea level pressure			Departure from normal precipitation		
	At Boise (inches)	Maximum when not at Boise		North Pacific	Mid-Pacific	South Pacific
		Inches	Place			
January—						
1900.....	30.26	30.30	Grand Junction, Colo.	-1.6	-0.6	-1.4
1901.....	30.18	30.32	do	-0.1	+1.0	+1.8
1902.....	30.30			-2.7	-3.9	-1.4
1903.....	30.23			-0.5	+0.3	-0.6
1904.....	30.30			-1.3	-3.6	-2.3
1905.....	30.26	30.41	Huron, S. Dak.	-2.0	-0.3	-0.3
1906.....	30.26			-1.2	0.0	+0.6
1907.....	30.06	30.26	Huron, S. Dak.	-1.3	+0.8	+2.8
1908.....	30.22	30.26	Pocatello, Idaho.	-1.2	+0.5	+1.3
1909.....	29.97	30.21	Chattanooga, Tenn.	+1.8	+6.9	+5.3
1910.....	30.27			+0.7	-1.2	-0.7
1911.....	30.12	30.29	Anniston, Ala.	-0.4	+6.3	+4.4
1912.....	30.24			+0.9	-1.0	-1.7
1913.....	30.21			+0.7	-0.6	-0.8
1914.....	30.02	30.18	Durango, Colo.	+5.9	+3.5	+6.7
1915.....	30.18			-1.3	+2.7	+2.3
1916.....	29.98	30.31	Miles City, Mont.	-1.0	+6.2	+8.3
1917.....	30.31			-2.7	-2.2	-0.3
1918.....	30.16	30.21	Roseburg, Oreg.	-0.8	-3.6	-2.0
1919.....	30.31	30.36	Grand Junction, Colo.	+2.0	-1.6	-1.9
1920.....	30.34			-1.1	-4.2	-2.2
1921.....	30.13	30.16	Fresno, Calif.	+1.6	+1.3	+0.7
1922.....	30.30			-3.9	-2.3	-1.6
1923.....	30.13	30.16	Sacramento, Calif.	+2.3	-2.0	+0.6
1924.....	30.38			-2.3	-2.2	-2.2
1925.....	30.24	30.30	Grand Junction, Colo.	-0.1	-2.8	-1.8
1926.....	30.33			-1.4	+0.1	-0.8
1927.....	30.22	30.28	Miles City, Mont.	-0.5	-1.0	-1.2
Average.....	30.21					
Normal.....	30.185					

¹ The isobars of the G. B. A. were so oriented as to give southerly winds over California and abundant rains.

Whether the G. B. A. shall be fully or only partially developed is, of course, not known in advance, and its varying intensity must be considered as perhaps wholly fortuitous.

In the 28 months shown in Table 1, 8 had mean pressure of 30.3 inches or greater; 12 mean pressures ranging from 30.15 to 30.29 inches (sea level), and the remainder had means ranging from 29.97, the lowest, to 30.13 inches.

The tendency of cyclones to circle around the periphery of anticyclones is well established and this fact is well exemplified in the G. B. A. Obviously then when the Great Basin is occupied by an anticyclone, cyclones must avoid that region, which they do by passing eastward along the border between the United States and Canada or crossing California south of latitude 40° north and moving thence east-southeast to the Gulf of Mexico. It so happens, however, that there is usually little opportunity for cyclonic storms to enter the continent south of the latitude above given because cyclonic storms owe their origin to weather conditions that exist farther north rather than over the Pacific west of the coast of southern California.

GREAT BASIN ANTICYCLONE INIMICAL TO PRECIPITATION IN CALIFORNIA

The lack of precipitation in generous quantities in Pacific Coast States when the Great Basin is occupied by an anticyclone is because the winds in these States are then generally land winds and both cold and dry. The opportunity for precipitation is absent.

In the 28 years covered by the data of Table 1, normal, or better, rains fell in California in 1901, 1907-1909,

distribution on the Pacific coast, high pressure being associated with deficient rainfall and vice versa.

Since the low-pressure months have for us the greatest interest, I have discussed them in some details in the paragraphs that follow.

JANUARY, 1907, AND 1909

Meteorological observations outside of continental United States for these months are not at hand, but

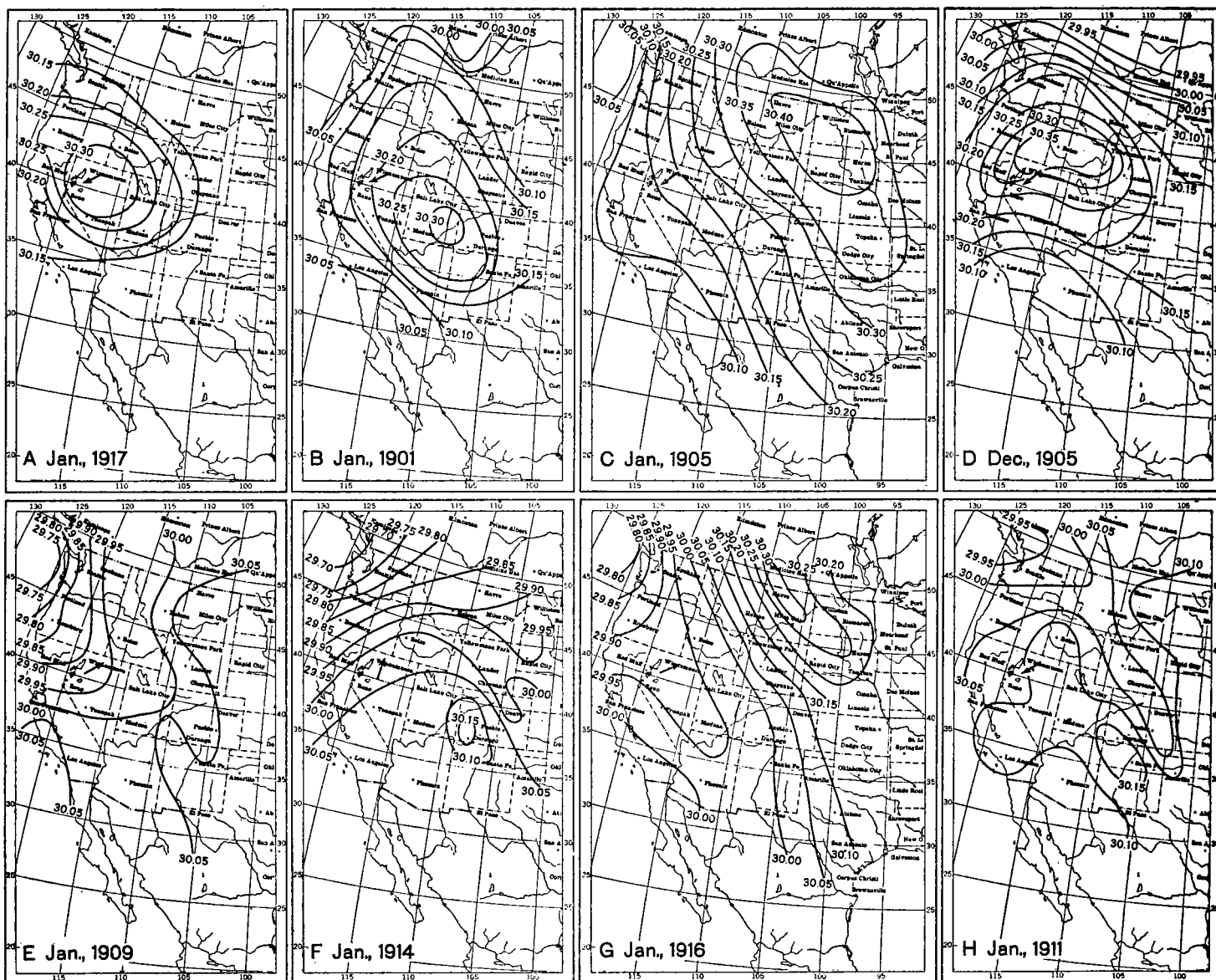


FIG. 2

1911, 1914-1916, and 1921, in all in four periods counting as a single period both of the three consecutive years 1907-1909 and 1914-1916. Four rainy periods in 28 years suggests the seven-year period about which Clough has written.² I have given in Table 1 the monthly precipitation departures for the north, middle, and south Pacific climatological districts as published in the MONTHLY WEATHER REVIEW. These data show how intimate is the relation of precipitation to the pressure

those of Pacific Coast States indicate quite clearly that for 1909, at least, pressure over the Gulf of Alaska was low and that pressure gradients on the Pacific coast were for southerly winds for the greater part of the month. (See chart E, fig. 2.)

It can be laid down with much confidence that months with more than normal precipitation in California are those in which pressure in the Gulf of Alaska is considerably below the average; as a consequence cyclonic wind systems, often of little intensity, impinge upon the land and sometimes, but not always, pass into the interior.

² Clough, H. W. An approximate seven-year period in terrestrial weather with solar correlation. MONTHLY WEATHER REVIEW 48:593.

In other words, the low-pressure center normally found over or near to the Aleutian group of islands is displaced to the southeast, the G. B. A. can not form, and southerly winds with abundant rains prevail in California.

JANUARY, 1911

The data for this month are less complete than for the two months next following; they show, however, an area of below-normal pressure in northwest United States and British Columbia protruding against an area of much higher pressure in the northwestern Canadian Provinces and Southeastern Alaska. Such a distribution, in theory at least, would prevent cyclonic storms from advancing eastward across the continent, yet actually three such storms entered the State of Washington and passed entirely across the continent. California had one of the wettest Januaries of record, yet not a single cyclonic storm was of sufficient continuity to cross the State.

The explanation is that part of the rain was caused by the storms that crossed Washington and part was due to weak cyclonic formations along the California coast that could not be charted. From this we learn that one or more barometric depressions in which cyclonic wind circulation is either absent or greatly weakened is of equal importance, so far as precipitation is concerned, as with a well-developed cyclonic storm.

JANUARY, 1914

A most remarkable month in that a very great depression of the barometer seems to have stretched across the Arctic and to have extended as far Equatorward as north latitude 40° in North America, Europe, and Asia. A series of cyclonic storms encircled nearly the entire globe in north latitudes 40° to 60° . Seven such storms passed onto the continent between 45° and 50° north, and gave the Pacific Coast States an abundant rainfall notwithstanding the relatively high latitude of entry of the storms.

JANUARY, 1916

In this month pressure was exceptionally low from Greenland and the Labrador coast across the north part of the Atlantic Ocean to Europe, the region of greatest depression being over Russia. Pressure was also low from Russia south to the Mediterranean and thence eastward to the Philippines. It was exceptionally high in Alaska, Spain, Portugal, and the western Mediterranean region. Concurrently with high pressure in Alaska several well-developed cyclonic storms entered southern California, giving torrential rains to that region. Just how the events above mentioned are inter-related is not known, although experience teaches us that prevailingly high pressure in the higher latitudes has a tendency to cause cyclonic storms to take a course farther south than usual.

CAN THE INTENSITY OF THE G. B. A. BE FORECAST?

The very intimate connection that subsists between pressure over Pacific Coast States and rainfall in California leads at once to the above query.

The method of correlation used to good advantage by Walker and others comes at once to mind. Since the drift of the weather is from west to east, one naturally thinks of the weather of the Pacific Ocean between the

North American coast line and, say, the coast of Japan. While the mass of observational material for this area is slowly increasing, it is yet scarcely practicable to construct monthly averages of pressure distribution over the ocean surface without the expedient of extrapolation to a rather large extent. The monthly averages derived from island stations are either too short or the island station is badly situated geographically; Honolulu, for example, is too far south to represent pressure changes in the north Pacific anticyclone, and the record of Alaskan stations at best is less than 12 to 15 years; nevertheless, I have correlated Alaska monthly pressure deviations with similar data for Boise, Idaho. The correlation coefficient for current deviations comes out $\gamma=0.23$, a result that agrees with empirical rules that have been developed by forecasters to the effect that the progressive movement of pressure formation from interior Alaska to southern Canada and the United States is a matter of a few days at most. It is not surprising therefore that the correlation coefficient, Alaska pressure with that of Boise, Idaho, three months later is too small to be of any significance. Progress along this line of inquiry therefore can not be expected with the available statistical material.

The present network of meteorological reports from the Pacific is rather closely confined to the great circle sailing routes between western United States and Canada and the Far East, including Australia and Honolulu, Hawaii Territory.

We deceive ourselves when we create the impression that a study of the current and accumulated data of the Pacific will point the way to seasonal forecasting for the North American Continent; nevertheless we should not on that account refrain from a sustained effort to summarize and place in convenient form for statistical analysis the current and accumulated meteorological data for the Pacific Ocean.

INFLUENCE OF THE ASIATIC ANTICYCLONE

There are at least two reasons why variations in the strength or position of the Asiatic anticyclone can have but little influence upon the weather of the North American Continent. The first is the uncertainty that arises in an attempt to determine the intensity and geographic position of the central area of this anticyclone. Walker used two stations—Eniseisk and Irkutsk—to represent central Siberia. The pressure at Eniseisk is much more variable than that of Irkutsk and, moreover, at times the variation at the two stations is in the opposite sense, particularly when the deviation from the normal is small. I have computed the quarterly variation by using the mean of the deviation at these two stations and compared that mean with quarterly mean deviations of pressure from the normal for the Great Basin region. This comparison shows that there is little or no prevision in the Asiatic anticyclonic pressures.

The second reason is that offshoots from the Asiatic anticyclone must, in general, move Equatorward over the ocean. In so moving, by reason of greatly reduced radiation from a water surface as compared with a land surface, they must decrease in intensity as they pass over the water; the original offshoots, moreover, probably never reach the American Continent, except as modified by the long oceanic journey and the pressure conditions encountered en route. On the other hand anticyclones that may move into northeastern Siberia from polar seas may easily drift over Alaska and thus in a measure affect the movement of cyclones over the United States.